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Air Pollution Assessment of Ethylene Dichloride

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Air Pollution Assessment of Ethylene Dichloride

R. JOHNS

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16. ABSTRACT Ethylene dichloride, a chlorinated hydrocarbon, is primarily used as an intermediate during the production of vinyl chloride and other commercially valuable compounds. The characteristic water solubility and vapor pressure of ethylene dichloride indicate that this compound will tend to presist in the hydrosphere and lithosphere; while its slow activity with peroxide radicals and ozone indicates atmospheric persistence as well. Industrial exposure is limited by Occupational Safety and Health regulations to 200 mg/m^3 (50 ppm). Ambient atmospheric measurements are not readily available. Inhalation of ethylene dichloride during acute exposure has been shown to produce central nervous system disorders as well as pathological effects in the liver, kidneys, and adrenals of humans, while chronic human exposure produces similar results. The no-lasting-effect level is quite high (1000 ppm for 1 hour and 3000 ppm for 6 minutes) indicating that detrimental exposure levels would have to be much greater. Although the compound does not appear to pose a significant environmental hazard, little information is available for assessment of potential long-term low level effects. As a result ethylene dichloride cannot be considered innocuous until additional health data is accumulated.

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ABSTRACT

Ethylene dichloride, a chlorinated hydrocarbon, is primarily used as an intermediate during the production of vinyl chloride and other commercially valuable compounds. The dispensive uses of ethylene dichloride (as an industrial solvent and extractant and as a fumigant and insecticide) constitute approximately 60 million pounds per year to the environment. It has also been estimated that 1.5 percent of total production is lost to the environment yielding a total of 129 million pounds in 1973. The characteristic water solubility and vapor pressure of ethylene dichloride indicate that this contamination will tend to presist in the hydrosphere and lithosphere, while the slow activity of the dichloride with peroxide radicals and ozone indicates atmospheric persistence as well.

Industrial exposure is limited by Occupational Safety and Health regulations to 200 mg/m^3 (50 ppm), which is identical to the recommended threshold limit value proposed by the American Conference of Governmental Industrial Hygienists. However, ambient atmospheric measurements are not readily available.

Inhalation of ethylene dichloride during acute exposure has been shown to produce central nervous system disorders as well as pathological effects in the liver, kidneys, and adrenals of humans, while chronic human exposure produces similar results. The no-lasting-effect level is quite high (1000 ppm for 1 hour and 3000 ppm for 6 minutes)

indicating that detrimental exposure levels would have to be much greater.

Although the compound does not appear to pose a significant environmental hazard, little information is available for assessment of potential long-term low level effects. As a result ethylene dichloride cannot be considered innocuous until additional data is accumulated.

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TABLE OF CONTENTS

		Page
I.	SUMMARY AND CONCLUSIONS	1
II.	AIR POLLUTION ASSESSMENT REPORT	8
	A. PHYSICAL AND CHEMICAL PROPERTIES	8
	B. EFFECTS	11
	C. AMBIENT DATA, POPULATION RISK AND MEASUREMENT TECHNOLOGY	18
	D. SOURCES	23
	E. CONTROL STRATEGY	28
REFERENCES		31

LIST OF ILLUSTRATIONS

Figure Number		Page
1	ETHYLENE DICHLORIDE - COMMERCIAL PATHWAYS	24
2	ETHYLENE DICHLORIDE PRODUCTION CAPACITY	25

LIST OF TABLES

Table Number		Page
I	ETHYLENE DICHLORIDE	9
II	ACUTE TOXICITY OF ETHYLENE DICHLORIDE	14
III	ETHYLENE DICHLORIDE PRODUCTION DATA	26

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I. SUMMARY AND CONCLUSIONS

Ethylene dichloride is a colorless liquid possessing good solvent properties for oils, fats, resins, and many organic chemicals. It burns with difficulty, but the vapor is explosive in air at concentrations of 6-16 percent by volume. The appreciable water solubility of the compound (9 grams/liter) and its moderately high vapor pressure tend to promote environmental persistence in water and soil as well as in the atmosphere. Ethylene dichloride hydrolyzes slowly to ethylene glycol at ambient temperatures, and rapidly under mildly acidic conditions (pH 4) at 160°C. Airborne ethylene dichloride reacts very slowly with peroxide radicals and ozone, showing half-lives of 10^3 to 10^7 days toward these reactions in the atmosphere. The compound is resistant to photochemical degradation. Ethylene dichloride is a useful synthetic intermediate, (attributable to the terminal chlorine atoms), and is used in the production of various industrial chemicals. Production of vinyl chloride accounts for 95 percent of domestic consumption.

Ethylene dichloride is toxic to mammals by inhalation, ingestion and dermal absorption. Acute human toxicity of ethylene dichloride vapor is documented primarily from accidents where dosage was uncertain. Without any lasting effects, human tolerance for the vapor is estimated at 4,000 mg/m^3 (1,000 ppm) for 1 hour and 12,000 mg/m^3 (3,000 ppm) for 6 minutes. Victims of acute exposure

suffer dizziness, tremors, mental confusion, nausea, vomiting and fatigue. Primary pathological effects of the compound are found in the liver, kidneys and adrenals. A threshold limit value (TLV) of 200 mg/m^3 (50 ppm) vapor concentration has been recommended by the American Conference of Governmental Industrial Hygienists. Chronic exposure to ethylene dichloride vapor at concentrations significantly above this level results in mild narcosis, nausea, headache and fatigue in humans, with pathological damage to the liver, kidneys and adrenals. Occupational safety and health regulations limit industrial atmospheres to 200 mg/m^3 (50 ppm) ethylene dichloride for 8-hour-average daily exposures.

Acute oral toxicity of ethylene dichloride in humans is documented by case histories of poisonings. An adolescent who ingested 15 ml of the chemical developed headache, nausea and vomiting within 2 hours. After one day, he showed depressed blood pressure, lowered blood glucose and elevated urinary albumen. Death occurred after 4 days from refractory hypotension. Autopsy revealed extensive necrosis of the liver, mild necrosis of the kidneys, and degenerative cell damage in the adrenals. General symptoms of oral poisoning are dizziness, stupor, nausea, cramps and respiratory congestion.

Animal studies have provided extensive data on inhalation toxicity of ethylene dichloride. At the acute level, rats showed

LC_{50}* values of 48,600 mg/m^3 for 32-minute exposures and 4,048 mg/m^3 for 432-minute exposures. The minimum lethal concentration for mice (120-minute exposure) was 35,000 mg/m^3. For guinea pigs, the comparable value was 14,200 mg/m^3 for 60-minute exposures. The symptoms of vapor exposure are similar in all mammals and are characterized by narcosis, lung irritation, vomiting, and injury to the liver, kidneys and adrenals. Autopsy of rabbits receiving lethal exposures to 12,400 mg/m^3 ethylene dichloride showed necrotic and hemorrhagic lesions of the liver and kidneys. Chronic exposure of rats, guinea pigs, rabbits and cats showed that all these animals tolerated a vapor concentration of 400 mg/m^3 for seventeen weeks (6 hours/day, 5 days/week) without apparent effect. A concentration of 2,000 mg/m^3 was found to be toxic to rats, guinea pigs and rabbits under similar conditions of exposure. Dogs tolerated 7-hour-daily exposures to 1,600 mg/m^3 for a period of 8 months without apparent symptoms. Exposure of female rats to 57 mg/m^3 for 4 hours per day during gestation caused decreased fertility and virility in the offspring.

In studies of the acute oral toxicity of ethylene dichloride to test animals, rats showed an LD_{50}** of 0.68 g/kg-body-weight. A value of 2.5 g/kg-body-weight was found for dogs. Oral

*LC_{50} - Concentration fatal to 50 percent of a sample population under stated conditions of exposure.
**LD_{50} - Dose fatal to 50 percent of a sample population under stated conditions of administration.

administration of the chemical at the sub-lethal level has been found to produce changes in the blood and liver of rats.

Ethylene dichloride has been found to have no carcinogenic activity in inhalation exposures of rats, rabbits, guinea pigs and monkeys. These animals were exposed to vapor concentrations of 405-1600 mg/m^3 for periods of 202-246 days. Further studies of carcinogenic activity are currently in progress at the National Cancer Institute. The compound is mutagenic toward fruit flies when eggs of the species are cultured in nutrient media treated with ethylene dichloride.

In the aquatic environment, the maximum level of ethylene dichloride which permits normal biological activity of invertebrates is 0.1 mg/l. Common waterborne microflora tolerate the chemical at concentrations up to 25 mg/l.

Ethylene dichloride vapor is monitored in the industrial environment for compliance with occupational exposure standards. However, measurements of the chemical in the ambient atmosphere are sparse. Atmospheric concentrations of the chemical downwind of production facilities may be predicted from hypothetical plant parameters, when analytical data are lacking. Predictions are based on estimates of production losses from the largest domestic ethylene dichloride plant. These were estimated to be 13.6 million pounds/year or 196 grams/second. An atmospheric diffusion model was used to estimate downwind atmospheric concentration of ethylene dichloride.

At a distance of 500 meters from the point of emission, it was estimated as 1855 $\mu g/m^3$. This concentration, at a location assumed to be near the plant property line, is seen to be about one hundred fold less than the threshold limit value of 200 mg/m^3. The corresponding population exposure is such that the dose received over a 75-year lifetime would be approximately equal to that received by a single-shift industrial worker in four months, assuming maximum permissible workplace concentration.

Dispersive uses of ethylene dichloride may expose various segments of the population to the chemical. It is used as an agricultural fumigant and insecticide, applications which are totally dispersive and inherently difficult to control. As a gasoline additive, the chemical undergoes losses to the environment throughout the extensive distribution chain which serves this market.

Measurement of airborne ethylene dichloride is straightforward. Gas chromatography is the method of choice, and modern electron capture detectors used in chromatography offer selectivity for halohydrocarbons as well as sensitivity at the parts-per-billion level. The chemical also responds to the halide lamp detector, a simple instrument which provides semi-quantitative measurement of airborne halohydrocarbons.

Domestic production of ethylene dichloride was 8.6 billion pounds (4.3 million tons) in 1974. It is, therefore, fourth in rank

among all manufactured organic chemicals. Ethylene dichloride has seen rapid growth during the last decade. This growth reflects increasing demand for vinyl chloride, for which it is the principal chemical intermediate. Vinyl chloride demand is sensitive to sales of PVC polymer, and hence, to general economic conditions. Domestic production capacity for ethylene dichloride is 12.3 billion pounds/year (6.15 million tons/year) and is concentrated in the Gulf Coast petrochemicals region. There are no known natural sources of the chemical, and no significant secondary sources can be identified.

It is estimated that 190 million pounds of ethylene dichloride were dispersed to the environment in 1974. Of this total, 60 million pounds would have been lost to the atmosphere due to the use of the compound as a fumigant or solvent, while the remainder would have been lost to both the atmosphere and hydrosphere during production operations.

Although ethylene dichloride is produced in large quantity, the principal uses of the chemical are non-dispersive. Estimation of downwind concentrations of the chemical near a hypotehtical production facility revealed a level of 1855 g/m^3, approximately 100-fold less than the threshold limit value of 200 mg/m^3. However, this estimate should be confirmed by monitoring data. Should additional plant controls be required, scrubbers, absorption towers and/or recycling loops would be effective. Ethylene dichloride is used as a lead scavenger in motor fuel. Therefore, loss of the chemical to

the environment is possible from the same distribution network as that of gasoline. The use of ethylene dichloride in gasoline is declining, and will be abandoned once leaded gasoline is eliminated from the market. Control of insecticidal uses of the chemical is largely dependent on the skill and judgment of the user. Adequate control of such highly dispersive uses may require legislative restrictions on the sale and use of the chemical.

In conclusion, ethylene dichloride does not appear to be a significant environmental hazard. However, since little information is available to assess potential long-term low level effects, or possible synergistic effects, the chemical cannot be considered environmentally innocuous.

The physical/chemical properties of ethylene dichloride suggest that transport in both atmospheric and aquatic environments with little degradation in feasible. Hence, it is suggested that ambient measurements be secured in those areas where its level is deemed highest.*

*Areas to be considered are boundaries of production facilities, agricultural facilities where it is used as a fumigant and insecticide, and segments of the gasoline distribution network where greatest gasoline emissions are known or suspected.

II. AIR POLLUTION ASSESSMENT REPORT

A. PHYSICAL AND CHEMICAL PROPERTIES

Ethylene dichloride is a colorless liquid possessing good solvent properties for oils, fats, resins, and many organic chemicals. The structure and principal physical properties of the chemical are shown in Table I. Ethylene dichloride is slightly flammable and burns with difficulty. In contact with flame, it is decomposed to hydrochloric acid and other irritant vapors. The vapor is explosive in air at concentrations of 6-16 percent by volume (1). Ethylene dichloride is miscible with most organic solvents, including all of the halohydrocarbons. The compound forms a binary azeotrope with water (8.1 volume percent) which boils at 71.9°C. The appreciable water solubility of the compound and its moderately high vapor pressure tend to promote environmental persistence in water and soil as well as in the atmosphere. Ethylene dichloride hydrolyzes slowly to ethylene glycol at ambient temperatures, and rapidly under mildly acidic conditions (pH 4) at 160°C. Airborne ethylene dichloride reacts very slowly with peroxide radicals and ozone, showing half-lives on the order of 10^3 to 10^7 days toward these oxidation reactions (2). The latter reaction produces vinyl chloride, α-chloroacetaldehyde, and other chlorinated products. The compound is resistant to photochemical degradation.

Ethylene dichloride is synthesized industrially by direct chlorination or oxychlorination of ethylene. The terminal chlorine atoms in the compound are moderately reactive, and make the chemical useful

TABLE I

ETHYLENE DICHLORIDE

Physical Properties

Chemical Formula	$ClCH_2-CH_2Cl$
Molecular Weight	98.97
Boiling Point	83.5°C
Melting Point	-35.4°C
Vapor Pressure, 25°C	87 mm Hg
Specific Gravity, liquid	1.25
Specific Gravity, vapor	3.4
Refractive Index, 20°C	1.4449
Solubility, water, 20°C	9.0 g/l
Solubility, octanol	∞
Conversion Factors @ 25°C/760 mm Hg	1 mg/liter 247 ppm 1 ppm 4.05 mg/m^3

Source: Kirk, R. E., Encyclopedia of Chemical Technology, Second Edition V. 5, p. 149, New York, Wiley, 1964.

as a synthetic intermediate. More than 95 percent of the domestic production of ethylene dichloride is used in the synthesis of other chemicals, principally vinyl chloride monomer (2). The monomer is produced by the reaction of ethylene dichloride with alcoholic alkali:

$$Cl - CH_2 - CH_2 - Cl \xrightarrow[\text{Alkali}]{\text{Alcoholic}} CH_2 = CHCl$$

Reaction of ethylene dichloride with ammonia yields ethylene diamine, whereas cyanide acts on the compound to form the dinitrile of succinic acid (1). These products also find use as synthetic intermediates for organic chemicals.

B. EFFECTS

Ethylene dichloride is absorbed through the lungs, from the gastrointestinal tract, and to some extent through the skin (3). It produces narcosis in mammals, in common with other halohydrocarbons. Primary pathological effects of the compound are found in liver, lungs, kidneys, and adrenals (4). The extent and nature of metabolism of ethylene dichloride are unknown (3).

Acute human toxicity of ethylene dichloride vapor has been documented primarily from accidental exposures where dose was uncertain. It has been estimated by McCollister et al. (4) that vapor concentrations of 4000 mg/m^3 (1,000 ppm) can be tolerated for 1 hour and 12,000 mg/m^3 (3,000 ppm) can be tolerated for 6 minutes without permanent effects. At high levels, the vapor is irritating to the eyes, nose and throat (3). Other symptoms are largely related to depression of the central nervous system or disturbance of the gastrointestinal tract. Patients suffer dizziness, tremors, mental confusion, headache, nervousness and fatigue (5). The heartbeat may be slowed and the blood pressure reduced. Gastrotestinal symptoms take the form of nausea, vomiting and anorexia (5). Severe vapor poisoning is known to result in clonic-tonic convulsions in some patients (5). The liver may become enalrged and tender, and is the primary site of pathological damage, which may also extend to the kidneys and adrenals (3).

A threshold limit value (TLV)* of 200 mg/m^3 (50 ppm) has been recommended for ethylene dichloride by the American Conference of Governmental Industrial Hygenists (6). Chronic human exposure to vapor concentrations significantly above this level result in mild narcosis, nausea, headache and fatigue (5). Overt symptoms are generally similar but less severe than those seen in cases of acute exposure. Pathological damage is found in the liver, kidneys and adrenals. For the protection of workers exposed to the chemical, Occupational Safety and Health regulations limit industrial atmospheres to 200 mg/m^3 (50 ppm) for 8-hour-average daily exposures (7).

Acute oral toxicity of ethylene dichloride in humans is documented by cases of accidental or intentional poisoning (8,9). In one case, an adolescent boy drank 15 ml of the chemical in anticipation of euphoric effects (8). Within two hours, he complained of headache, vomiting and loss of balance. After a day, he showed depressed blood pressure, lowered blood glucose, and elevated urinary albumen. The blood showed an elevated calcium level and a protracted coagulation time. The patient was revived from a cardiac arrest on the third day after poisoning but died two days later from refractory hypotension. Autopsy revealed extensive necrosis of the liver, leaving only scattered vacuolated cells. The kidneys, which were yellow and swollen, showed collapse of the collecting tubules and occasional necrosis of focal

*Airborne concentration which induces no physiological response after repeated exposure.

epithelial cells. The adrenals were of normal shape and size, but microscopic examination revealed vascular congestion and focal degenerative cell damage. In a second case of acute oral poisoning, a 25-year-old man ingested an undisclosed quantity of ethylene dichloride but recovered after several months of hospital treatment (9). He suffered severe toxic hepatocellular damage, hepatic coma and subsequent cirrhosis, but renal damage was relatively mild. Luzhnikov has noted changes in EKG, phasal activity of the heart and hemodynamics in a study of many cases of oral poisoning with ethylene dichloride (10). Generalized symptoms of acute oral poisoning include dizziness, headache, stupor, nausea, cramps and respiratory congestion. Chronic oral toxicity in humans is sparsely documented.

Inhalation toxicity of ethylene dichloride has been studied extensively using laboratory animals. Acute toxicity data are shown in Table II. The symptoms of vapor exposure are generally similar in all mammals and are characterized by narcosis, lung irritation, nausea, vomiting, and injury to the liver, kidneys and adrenals (11). Heppel et al. (12) found that single 7-hour exposures at 12,400 mg/m^3 were fatal to mice, rats, guinea pigs and rabbits. Rabbits exposed by Lioia (13,14) to this vapor concentration for an unstated time showed acute poisoning with necrotic and hemorrhagic lesions of the liver and kidneys. No significant changes in blood and spinal marrow were found from acute exposure, but chronic exposure under unstated conditions produced anemia and marrow poisoning (13). Chronic vapor exposure of rats,

TABLE II

ACUTE TOXICITY OF ETHYLENE DICHLORIDE

ANIMAL	ROUTE	DOSE	DOSAGE	EXPOSURE	REFERENCE
Rat	Inhal.	LC_{50}	48,600 mg/m^3	31.8 Min.	Spencer et al, Arch. Ind. Hyg. Occ. Med. 4, 482 (1951)
	Inhal.	LC_{50}	4,048 mg/m^3	432 Min.	Spencer, Op. Cit.
	Oral	LD_{50}	0.68 g/kg		McCollister et al, Arch. Ind. Health 13, 1 (1956)
Dog	IV	MLD	0.175 g/kg		Barsoum et al, Quart. J. Pharm. Pharmacol, 7, 205 (1934)
	Oral	LD_{50}	2.5 g/kg		Barsoum et al, Op. Cit.
Rabbit	Subcut.	MLD	1.6 g/kg		Barsoum et al, Op. Cit.
Mouse	Inhal.	MLC	35,000 mg/m^3	120 Min.	Lazarew, Arch. Exp. Path. Pharmakol, 141, 19 (1929)
Guinea Pig	Inhal.	MLC	14,200 mg/m^3	60 Min.	Sayers et al, Pub. Hlth. Reporter, 45, 225 (1930)

LC_{50} Concentration lethal to 50 percent of a sample population under stated experimental conditions.

LD_{50} Dose lethal to 50 percent of a sample population under stated experimental conditions.

MLD Minimum lethal dose under stated experimental conditions.

MLC Minimum lethal concentration under stated experimental conditions.

guinea pigs, rabbits and cats has been studied by Hofmann (15). These animals were exposed six hours per day, five days per week, for a seventeen-week period. All of the species tolerated a vapor concentration of 400 mg/m^3 without apparent effect, but a concentration of 2000 mg/m^3 was found foxic to rats, guinea pigs and rabbits. Spenser *et al.* have reported the results of animal exposures of seven hours per day, five days per week for a six-month period (11). The maximum vapor concentrations tolerated under these conditions were 1600 mg/m^3 for rabbits, 800 mg/m^3 for rats, and 400 mg/m^3 for guinea pigs and rhesus monkeys. Dogs are reported to tolerate 7-hour daily exposures to 1600 mg/m^3 for a period of 8 months without apparent symptoms; autopsy indicates slight fatty degeneration of the liver (11). Chronic intoxication by mixed vapors of ethylene dichloride and gasoline at unstated levels has been found to produce marked changes in the frequency and duration of the menstrual period in rats (16). Exposure of females to 57 mg/m^3 ethylene dichloride vapor for four hours per day during gestation causes decreased fertility and virility in the first progeny (17).

Oral toxicity of ethylene dichloride to test animals is sparsely documented. Acute toxicity data for rats and dogs are shown in Table II. At a sublethal level, doses of 3.7 ml/kg-body-weight, administered orally to dogs, cause retching, vomiting, marked salivation, and incoordination, but the animals recover rapidly to good health (18). Kagramanov (19) has reported that oral administration (to

rabbits) of 1.2 mg/kg-body-weight causes changes in the fibrinolytic activity in the blood. Oral ethylene dichloride doses of 766 mg/kg-body-weight have been found to decrease the level of sulfhydryl groups in the blood and liver of rats (20).

Ethylene dichloride is absorbed through the skin of mammals, but large doses are required to cause systemic poisoning (3). Rabbits survive a dose of 1.26 g/kg-body-weight, though severe skin irritation and moderate edema result (3). Subcutaneous injection of 1 ml/kg-body-weight in young white rats is fatal to 35 percent of the animals within 24 hours (21).

Ethylene dichloride was found to have no carcinogenic activity in inhalation exposures of rats, rabbits, guinea pigs and monkeys (2). These animals were exposed to vapor concentrations of 405-1620 mg/m^3 for periods of 202 - 246 days. As part of their overall program in evaluation of chlorinated hydrocarbons, the National Cancer Institute is reevaluating the carcinogenicity of ethylene dichloride. It has been shown to be mutagenic toward fruit flies when eggs of the species are cultured in nutrient media treated with unspecified amounts of ethylene dichloride (22). Treatment for one hour resulted in a mutation rate of about 2.6 percent, whereas 24-hour treatment resulted in a rate of 25-30 percent mutations.

In the aquatic environment, it has been found that the maximum level of ethylene dichloride which permits normal biological activity of invertebrates is 0.1 mg/l in water (23). This study also shows

that common waterborne microflora tolerate the chemical at a concentration of 25 mg/l.

C. AMBIENT DATA, POPULATION RISK AND MEASUREMENT TECHNOLOGY

Ethylene dichloride vapor is monitored in the industrial environment. Occupational Safety and Health regulations limit industrial atmospheres to 200 mg/m^3 (50 ppm) for 8-hour-average daily exposures of workers (7). However, ambient measurements of the chemical in the open atmosphere are rare. A threshold limit value of 200 mg/m^3 (50 ppm) has been recommended by the American Conference of Governmental Industrial Hygienists (6).

Routine ambient measurements of atmospheric ethylene dichloride outside of the occupational environment have not been made. From an examination of available reference material, no atmospheric surveys in metropolitan areas or near industrial sources of the chemical have been reported. Data are available on production losses associated with ethylene dichloride manufacture, and these may be used to develop estimates of population exposure downwind of manufacturing plants, using a model described below.

Atmospheric concentrations of ethylene dichloride downwind of production facilities may be estimated from hypothetical plant parameters, even though analytical measurements are lacking. Total production losses from domestic ethylene dichloride plants were estimated to be 129 million pounds in 1973, or 1.5 percent of production (2). The capacity of the largest domestic production facility is 1,300 million pounds, but since the industry as a whole operated at 70

percent of capacity in 1973, production losses are estimated on this basis to be 13.6 million pounds/year or 196 grams/second. This loss represents the maximum emission rate and hence the maximum downwind population risk from any domestic ethylene dichloride facility.

Emission rates of ethylene dichloride at production facilities can be used in a Gaussian plume equation* according to Turner (24) to predict downwind atmospheric levels of the chemical in surrounding neighborhoods. The basic diffusion equation must be modified, however, due to the effect of the plant itself on the flow of air. Mechanical turbulence in the wake of a building tends to produce aerodynamic downwash, resulting in the fairly rapid diffusion of a gaseous emission down to the ground. This region of disturbed flow extends downwind a distance equal to several times the height of the building. While this situation does not result in a Gaussian distribution plume, it is proposed that a modification of the usual formula still can be employed.

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*Ground level downwind concentrations resulting from a point source are predicted by the following equation:

$$\chi(x, 0, 0; H) = \frac{Q}{\pi \sigma_y \sigma_z u} \exp\left[-1/2 \left(\frac{H}{\sigma_z}\right)^2\right]$$

where: Q = uniform emission rate (grams/sec)
u = mean wind speed affecting the plume (meters/sec)
H = effective stack height, that is sum of stack height plus plume rise (meters)
σ_y = horizontal dispersion coefficient evaluated in terms of downwind distance to the point for which the contration is being computed (meters)
σ_z = vertical dispersion coefficient evaluated in terms of downwind distance to the point for which the concentration is being computed (meters)
χ = ground level concentration on plume axis (grams/m^3)

This is because the turbulent mixing in the wake of the building is assumed to be distributed uniformly in the vertical direction, analogous to the situation wherein a plume is trapped below an inversion layer. A limited vertical mixing height can be modeled using the equation:

$$\chi(x,0,z;\ H) = \frac{Q}{\pi\sigma_y u\ (.8L)}$$

where L is the limit of the mixing depth. In the case of an isolated rectangular building it is assumed that L equals 1.5 times the building height.

In addition there is a horizontal wind turbulence which is assumed to result in an initial horizontal plume spread equal to the width of the building normal to the wind direction. This is analogous to an area source emission with the area equal to the building top. This can be modeled using a further modification of the basic Gaussian diffusion equation. A virtual point source is assumed upwind of the building at a distance where the plume spread (for the given stability conditions) would equal the crosswind width of the building. The modified diffusion equation is, therefore:

$$\chi(x,0,z;\ H) = \frac{Q}{\pi\sigma_y' u(1.2h)}$$

where h is the building height and σ_y' is based on the downwind distance to the receptor point, plus the upwind distance to the virtual point source.

The estimated ethylene dichloride emission rate, Q, from the largest domestic production facility, was used in the foregoing equation to derive the atmospheric concentration of the chemical at a point 500 meters downwind of the plant. This atmospheric concentration was estimated to be 1855 $\mu g/m^3$ (0.458 ppm) under an assumed wind velocity of 6 m/sec.

The estimated downwind atmospheric concentration of ethylene dichloride near production facilities is seen to be about one hundredfold less than the threshold limit value of 200 mg/m^3. The population exposure under the foregoing conditions is such that an exposure of 359 days, or approximately one year, would be required to accumulate the maximum dose received by an industrial worker in one 8-hour working day. The downwind dose during a 75-year lifetime would be approximately equal to that received by the single-shift worker in four months.

Dispersive uses of ethylene dichloride may result in the exposure of various segments of the population to the chemical. Ethylene dichloride is used as an additive in leaded motor fuel, hence it may be lost to the environment throughout the extensive distribution chain which serves the gasoline market. The chemical is used commercially as a solvent and extractant, but under conditions of industrial control. It is not available as a consumer product. Ethylene dichloride is used as an agricultural fumigant and insecticide, applications which are totally dispersive and inherently difficult to control. Although

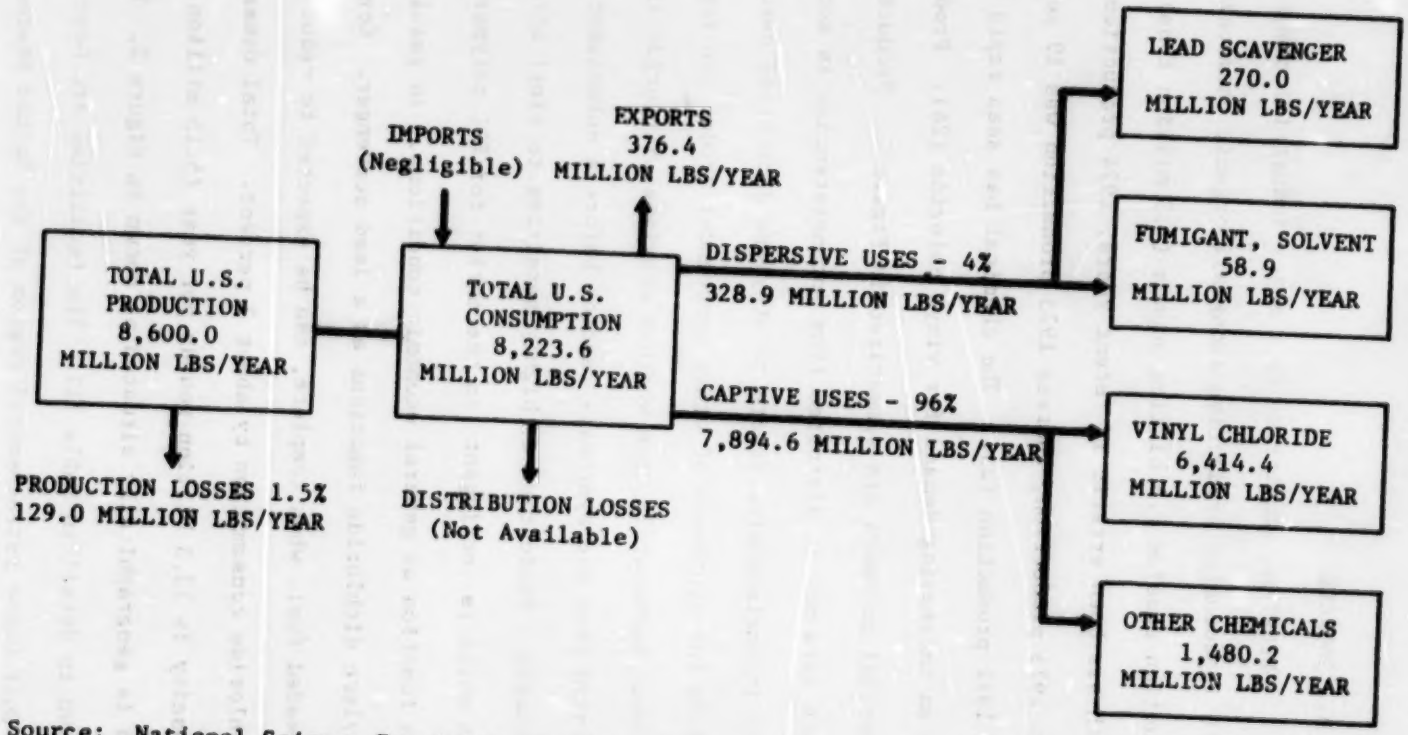
no data are available, it is possible that fumigation of enclosed grain storage areas may entail exposure of workers, bystanders and neighboring residents to excessive atmospheric concentrations of the chemical.

Measurement of airborne ethylene dichloride is straightforward. A classical procedure, useful in laboratories lacking extensive instrumentation, is based on hydrolysis of the compound and titration of the liberated chloride. This procedure is non-specific since it detects other organohalogen compounds. For specificity and maximum sensitivity, gas chromatography is the method of choice. Modern electron capture detectors offer selectivity for halohydrocarbons as well as extreme sensitivity to these compounds. Ethylene dichloride responds to the halide lamp detector, a simple instrument which is specific for organohalogen gases. It provides a qualitative or semi-quantitative indication of the presence of halogen compounds at a detection level of about 50 ppm, corresponding to 200 mg/m^3 of ethylene dichloride.

D. SOURCES

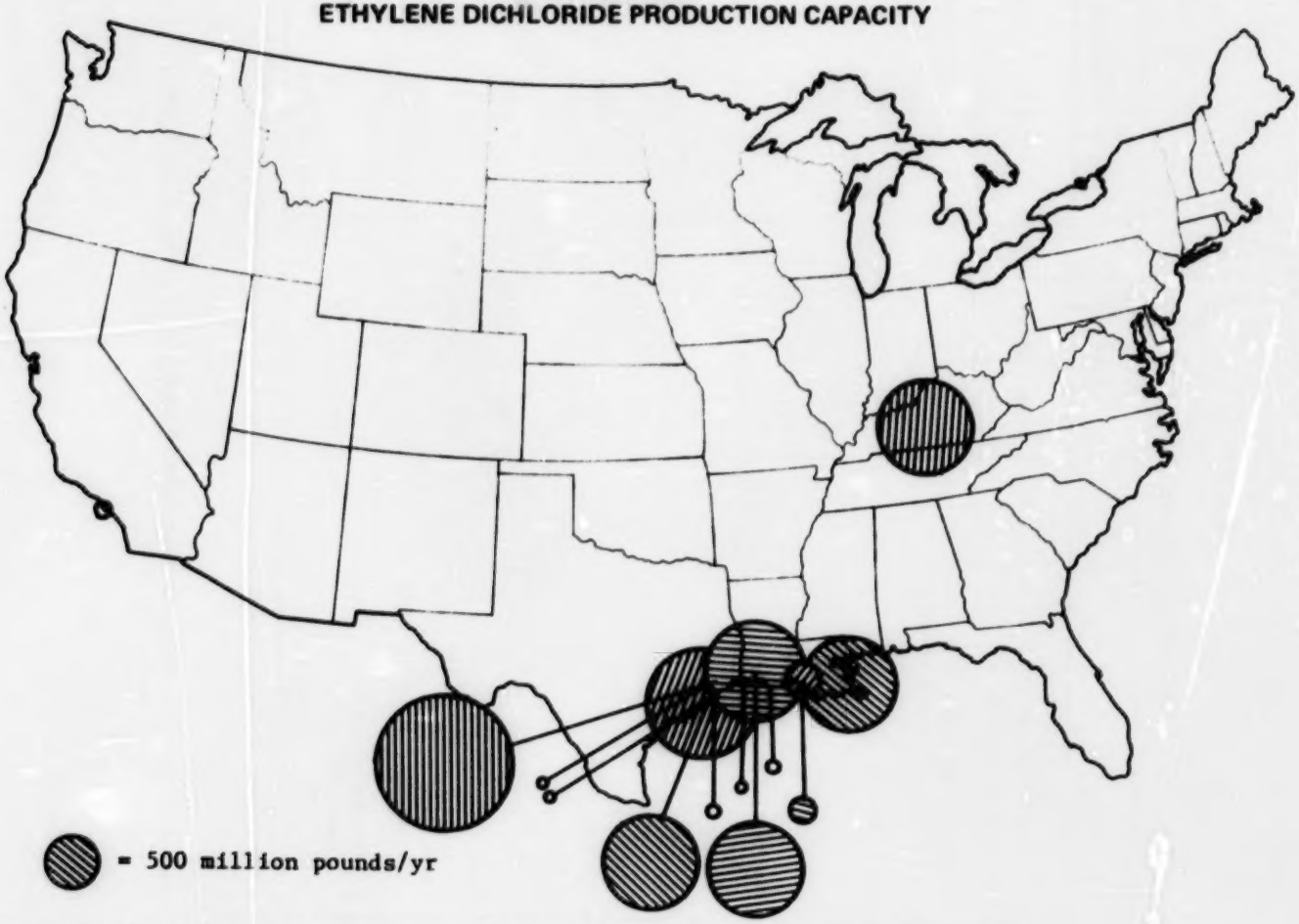
Ethylene dichloride is a major industrial chemical, ranking fourth in domestic production among all organic chemicals. Domestic production equaled 8.6 billion pounds (4.3 million tons) in 1974 (25). Growth has been erratic in recent years; 1974 production was 17 percent below 1973 production, whereas 1973 production was 19 percent higher than 1972 production (25). The chemical has seen rapid long-term growth from an increasing demand for vinyl chloride (26). Production and commercial pathways are summarized in Figure 1. Production and growth data may be distorted from inconsistencies in accounting (25). These inconsistencies relate to ethylene dichloride used as an intermediate for synthesis of other compounds; production reporting depends somewhat haphazardly upon whether ethylene dichloride is actually isolated from the synthesis reactor before a subsequent reaction is initiated. Production is highly sensitive to vinyl chloride consumption which is contingent on the market for PVC polymer; this demand is a function of general economic conditions. In gasoline, ethylene dichloride functions as a lead scavenger. Conversion to unleaded fuel, when complete, can be expected to reduce ethylene dichloride consumption by about 3 percent. Total domestic production capacity is 12.3 billion pounds per year (5.15 million tons/year)(27) and is geographically situated as shown in Figure 2. These data are shown in detail in Table III. The facilities are heavily concentrated in Gulf Coast petrochemical region of the United States.

FIGURE 1
ETHYLENE DICHLORIDE–COMMERCIAL PATHWAYS


TOTAL U.S. PRODUCTION 8,600.0 MILLION LBS/YEAR
PRODUCTION LOSSES 1.5% 129.0 MILLION LBS/YEAR
IMPORTS (Negligible)
EXPORTS 376.4 MILLION LBS/YEAR
TOTAL U.S. CONSUMPTION 8,223.6 MILLION LBS/YEAR
DISTRIBUTION LOSSES (Not Available)
DISPERSIVE USES - 4% 328.9 MILLION LBS/YEAR
CAPTIVE USES - 96% 7,894.6 MILLION LBS/YEAR
LEAD SCAVENGER 270.0 MILLION LBS/YEAR
FUMIGANT, SOLVENT 58.9 MILLION LBS/YEAR
VINYL CHLORIDE 6,414.4 MILLION LBS/YEAR
OTHER CHEMICALS 1,480.2 MILLION LBS/YEAR

Source: National Science Foundation Panel on Manufactured Organic Chemicals, SRI Data, 1975.

FIGURE 2
ETHYLENE DICHLORIDE PRODUCTION CAPACITY



Source: Stanford Research Institute. 1975. Directory of Chemical Producers, Menlo Park, California.

TABLE III

ETHYLENE DICHLORIDE PRODUCTION DATA

Producer	Location	Capacity Million Lbs/Year
Allied Chem. Corp.		
Indust. Chems. Div.	Baton Rouge, La.	650
Continental Oil Co.		
Conoco Chems.	Westlake, La.	1000
Diamond Shamrock Corp.		
Diamond Shamrock Chem. Co.		
Electro Chems. Div.	Deer Park, Tex.	260
Dow Chem. U.S.A.	Freeport, Tex.	1300
	Oyster Creek, Tex.	1100
	Plaquemine, La.	1160
Ethyl Corp.	Baton Rouge, La.	550
	Pasadena, Tex.	260
The B. F. Goodrich Co.		
B. F. Goodrich Chem. Co., div.	Calvert City, Ky.	900
PPG Indust., Inc.		
Chem. Div.		
Indust. Chem. Div.	Lake Charles, La.	1000
PPG Indust. (Caribe)	Guayanilla, P.R.	835
Shell Chem. Co.		
Base Chems.	Deer Park, Tex.	1200
	Norco, La.	1165
Stauffer Chem. Co.		
Plastics Div.		
Polymers West	Carson, Calif.	300
Texaco Inc.		
Jefferson Chem. Co., Inc., subsid.	Port Neches, Tex.	70
Union Carbide Corp.		
Chems. and Plastics Div.	Taft, La.	150
	Texas City, Tex.	150
Vulcan Materials Co.		
Chems. Div.	Geismar, La.	240
		TOTAL 12,290

Source: Stanford Research Institute, Directory of Chemical Producers. Menlo Park, CA, 1975.

Dispersive uses of ethylene dichloride amount to about 60 million pounds per year (30,000 tons/year). These include uses as an industrial solvent and extractant, and also the application of the compound as a fumigant and insecticide. As can be seen from Figure 1, total loss of ethylene dichloride to the environment during use and production is about 188 million pounds per year (94,000 tons/year). There is no indication of the existence of natural sources of the chemical, and no significant secondary sources can be identified.

E. CONTROL STRATEGY

Ethylene dichloride is produced in large quantity. The principal uses of the chemical are non-dispersive. More than 95 percent of production is used in the synthesis of other chemicals, often using unit processes which are integrated with ethylene dichloride production. Environmental losses from handling, storage and distribution are diminished or avoided through integrated plant design. Downwind atmospheric concentrations of ethylene dichloride near production facilities have been estimated from product loss data and found to represent generally acceptable levels of the chemical. These estimates should be supplemented with monitoring data. If additional emission controls are needed at production facilities, scrubbers, charcoal absorbers and/or recycling loops would be suitable.

In its major dispersive use, ethylene dichloride is employed as an additive in leaded gasoline. In this application, the chemical functions to scavenge lead oxide residues from internal combustion engines through conversion of the oxide to volatile lead chloride. Because of the complex distribution chain which serves the gasoline market, small amounts of ethylene dichloride are dispersed to the environment through evaporation and spillage of the fuel. These losses are significant to the total environmental burden of ethylene dichloride. However, they should present no significant hazard to localized population segments since the concentration of the chemical in gasoline is only about 0.05 percent. Ethylene dichloride undergoes combustion as the gasoline is used. This application is therefore

dispersive only in the handling and distribution of gasoline. The use of ethylene dichloride in fuel is presently declining, and will be abandoned once leaded gasoline is eliminated from the market.

Uses of ethylene dichloride as a fumigant and solvent are highly dispersive, although they account for only a small part of demand. Solvent applications are probably confined to the industrial environment, but fumigant operations are carried out under field conditions where control may be lax or difficult. Control of fumigant applications is largely dependent on personnel training and product application data. Adequate control of such highly dispersive uses may require legislative restrictions on sale and use of the chemical.

There are no data available on atmospheric accumulation of ethylene dichloride. As with other chemicals, it would be valuable to balance the rate of loss to the atmosphere against the sink capability of the environment for this chemical. The slow rates of reaction of ethylene dichloride with atmospheric oxidants suggest that the chemical may be highly persistent. Should future studies indicate a significant accumulation of ethylene dichloride in the atmosphere, a major control strategy should be implemented to limit sources and restrict dispersive uses of the chemical.

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